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NEW TOOLS AND METHODS IN FOREST MENSURATION^{1/}

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Since the general theme of the 1966 symposium is "Measuring the Southern Forest," I expect many of the other participants to describe new methods, and a few of them to mention new tools. I hope they do, because it is difficult to find much that is really new in forest mensuration. However, before preparing my contribution, I tried to identify some new things that would not be better covered by other speakers.

To find these things, I conducted an informal mail survey of selected foresters in the South, describing my subject and asking for suggestions about a few important new tools and methods in mensuration. This was a most successful survey. I received an 83-percent response and, without too much finagling with the results, found that each of the same three categories was mentioned by 80 percent of the respondents. Each of another three categories received 20 percent of the votes.

The three important categories of new tools and methods in forest mensuration were: (1) instruments for measuring upper stems

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of standing trees; (2) three-P sampling or other statistically designed cruising methods; (3) use of digital computers or automatic data processing.

These three categories may overlap what other speakers are covering. However, the list of topics showed that no one else was assigned instruments as a specific subject. I checked with Al Bickford to see what he planned to say about "Sampling Methods," and with George Furnival to see what he was going to cover under "Computer Applications." Neither of them had in mind the same aspects of these subjects that I want to describe, so I was quite happy with the outcome of my survey.

Instruments for Measuring Upper Stems of Standing Trees

Most of these instruments can measure upper stem diameters from a distance. This suggests a strong concern with the measurement of trees before they are scheduled for felling. This, in turn, implies a recognized need for better presale volume or value estimates, improved inventories of stands not scheduled for early felling, or for repeated measurements of trees or stands from which accurate estimates of growth can be made.

The capabilities of the instruments vary. Unfortunately, and almost predictably, the most accurate is the most expensive. However, I feel that the expressed need for such instruments will eventually lead to the development of new devices. These won't be as expensive as the highest cost ones today--but don't expect to buy a good one in a dime store.

These instruments measure in the field the actual dimensions of all parts of each sample stem. This allows direct estimates of volume in each of several value or product classes. These direct estimates avoid the bias of volume tables prepared by measurement of trees that are often not representative of the stand being measured. Furthermore, volume tables seldom permit breakdown into value or product class.

The most accurate instrument for measuring upper stems that I have used is the Barr & Stroud rangefinder dendrometer. Last fall, five of us at the Pacific Northwest Experiment Station tested its accuracy. For eight trees 15 to 26 inches in diameter, at distances of 66 to 144 feet, the average coefficient of variation (CV) of diameter was 0.88 percent. A single instrument setup was used for each tree and a small tag was put on the front of the tree to indicate point of measure-

ment. Each observer measured each tree twice. The CV includes observer, repetition, and tree interactions with these. On the same trees, the CV of extremely careful caliper measurements, taken in the same direction as the dendrometer readings, was 0.42 percent. The difference between the means of eighty dendrometer measurements and forty caliper measurements was 0.07 inch. The CV of basal area for the dendrometer, including difference between instruments, was 2.5 percent. Gosenbaugh (1963) reported 3.9 percent CV of basal area measurement on some pines at Crossett, but he included aspect as a variable, which would increase variation somewhat.

In our test, we got a CV of 0.90 percent for slope distance measurements against 0.18 percent for steel tape. The CV for dendrometer height determinations was 1.16 percent. This was not compared with other height measurements; however, this CV and that for basal area suggest that volume will be predicted within the 4 percent found by Gosenbaugh at Crossett.

In another test last summer, using the dendrometer in an eighty-year-old Douglas-fir, permanent sample plot, we measured seventeen trees. Excluding one tree with a broken top, we found that our standard volume table was overestimating the volume of small trees by 12 percent and underestimating the volume of big trees by 10 percent. (Tree diameters were from 11 inches to 24 inches.) For the tree with a broken top, direct measurement was much easier than using the volume table. This volume would be the total for a tree whose height included the fifty-foot (more or less) missing tip, with a deduction for the tip volume based on this guessed length and the estimated diameter at the break (13 inches).

A comparison of dendrometer-measured gross volumes of over a hundred trees with those based on the local volume tables actually used in one Oregon timber sales appraisal showed an overestimate of 9 percent for the volume tables.

These few examples are cited to indicate the gains in accuracy that may be expected when upper stems are measured. Instruments other than the Barr & Stroud dendrometer, mentioned by my respondents and others, include Wheeler's optical calipers, McClure's mirror caliper, Bitterlich's Spiegel-Relascope, and the Zeiss Teletop. I probably should add a couple: mil-scale binoculars and the Liljenstrom dendrometer. Some of these instruments aren't exactly new.

I do not have data from comparable tests showing the relative accuracy of all these different instruments. These tests are not

necessary to rank them in probable order of relative accuracy, since their operating principles can be used for this purpose.

For two reasons, instruments that displace the image of one side of a tree so that it can be aligned with the other side will be more accurate than those that require alignment of two reference marks with the two sides of the tree. The first reason is that there are only two lines to bring into coincidence instead of four. The second advantage for displaced images is that slight movement of the instrument, or the tree, will not interfere with alignment.

An instrument that adjusts the displaced image so that amount of adjustment can be read after the two images are brought into coincidence will be more accurate than one which needs to be read while the two sides of the tree are aligned.

Magnification will improve accuracy of alignment. However, the wrong telescope might do as much harm as good. Some defects that could be introduced through poor optical design are: too small a field of view, reduced illumination of image, and too small an exit pupil for optimum resolution of the image.

A telescopic instrument has an advantage other than magnification, if it is desired to use an internal scale to measure relative width of a tree--the reference marks and image of the tree are both in the focal plane of the eye lens. This does away with the nearly impossible job of clearly seeing a tree at a distance and reference marks close to the eye. Such a telescopic instrument must be mounted on a staff or tripod to eliminate instrument movement, but even so, movement of the tree by wind will reduce accuracy.

How then, would I rank these other instruments in order of probable accuracy? There are two parts to this: repeatability of measurements (or precision) and lack of bias. Precise instruments are not necessarily accurate because they may be biased.

First in rank would be Wheeler's telescopic optical calipers, which about equal the Barr & Stroud dendrometer in overall accuracy. First models of the telescopic calipers lacked a sharp separation of the two images. Despite this problem, repeated readings on the same point on a tree by different observers fell in a narrow range.

The Zeiss Teletop should be equally accurate for trees under 12 inches and not quite so accurate for trees 12 inches to 24 inches since two separate readings are required.

Wheeler's simple penta-prism calipers, which have been in use in the South for about three years, would probably rank next. The use of penta prisms practically eliminates bias. These calipers probably would be better than mil-scale binoculars for swaying upper stems but not so accurate for form class determinations, provided a tripod was used with the binoculars and a reticle with a suitable scale was substituted for the mil-scale.

I have not examined a Liljenstrom dendrometer, but I suppose it would be about as accurate as a modified binocular. These last two instruments require careful calibration and accurate determination of slope distance to eliminate bias.

McClure's mirror caliper should be a trifle less accurate than the prism calipers because the reading is made while the two sides of the tree are lined up and, also any deviation from parallelism of the mirrors will introduce bias. The Spiegel-Relascope would rank next because it requires four-way alignment and accurate distance determinations.

These accuracy ratings do not necessarily rank the instruments in order of utility for practical field measurement. Further, the differences in accuracy may be relatively small. A test, similar to the one we made of the rangefinder dendrometer, would probably find a CV of diameter measurement of about 2 percent or a little more for the Spiegel-Relascope--although a recent article in Malayan Forester (Brunig, 1964) suggests a CV closer to 1 percent. However, the Spiegel-Relascope has the advantage of automatic slope correction and can also be used as a clinometer. These features make it a very useful field instrument.

I would expect CV's of 0.75 to 2.5 percent for most of these instruments in determining diameters. Some would have to be used at fairly short distances to stay in this range. Because of stem irregularities, telescopic instruments are not likely to demonstrate much greater accuracy than 0.75 percent, unless measurements are made on telephone poles or repeated measurements are made by people with exceptionally good memories. The easiest trees to measure accurately are probably those with smooth bark, and possibly the hardest are trees with large plates of bark. With Douglas-fir, plates of bark six to twelve inches long can stand out on the silhouette one-quarter to one-half inch. If the approximate level of measurement is at the top or bottom of one of these plates, large discrepancies in successive readings can occur.

Diameter measurement is only one part of upper stem measurement. The only new gadget for height measurement, mentioned by my respondents, was the fiber glass extension pole. I think this is significant, because I have yet to find a really good clinometer. Something like the Suunto, with a drum at least twice the size, a well-illuminated, easily read scale, and a better sighting arrangement should not be too expensive and would be an improvement over what is now available. The World War II Navy Position Angle Finder was such an instrument, but apparently is no longer manufactured.

Brendemuehl and Baker, 1965, of the Southern Station, recently described a sectional aluminum pole which they claimed was more convenient than the telescoping fiber glass pole. I can think of several advantages which were not mentioned. After we used the fiber glass pole in the rain, it took about a week to dry the inside of it. Also, in the rain, one of the top sections occasionally unlocked while the pole was being extended vertically--if not noticed, this could cause errors.

Three-P Sampling

All I want to say about sampling methods is to report briefly on the gain in accuracy found in one test of three-P sampling (Grosenbaugh, 1964), plus dendrometer measurements, in the Northwest (Johnson, et al.). "Three-P" means probability proportional to prediction, so three-P is a form of variable probability sampling. It is used in sales appraisals where an ocular estimate (prediction) can be made of each tree, not in inventories where only a small fraction of the population is examined. It is most efficient when the prediction is actually proportional to the variable of interest, whether the latter be dollars of stumpage or volume of wood. In effect, it is a kind of nearly continuous stratification, where each level of prediction is a stratum. The number of units in the sample and error of estimate can be estimated fairly closely, but number in the sample cannot be specified exactly in advance. Since the outcome of samplings can be a useful guide to design of other similar sampling, results of this Northwest trial may be useful to some of you.

In a presale cruise of 1-1/2 million board feet of old-growth ponderosa pine, three-P sampling had a standard error of estimate of 4 percent against 9 percent for a standard one-in-twenty tree cruise. This is not a real measure of relative accuracy, since the standard errors measure different kinds of variation. The three-P error is based on the variation of the ratio of actual volume measured by the dendrometer to a local volume table estimate based on measured

diameter. This diameter measurement was substituted for volume estimates to get more uniformity than we could expect from ocular estimates of two markers. Thus, three-P error measures the deviation of measured from estimated volume and gives limits within which total volume would be expected to fall if all trees were measured.

In the one-in-twenty cruise, the 9-percent error of estimate is based on the variation of estimated volumes within the sample. These estimates were based on taped diameters, ocularly estimated number of logs, an average form class, and a volume table. The error of estimate includes no allowance for possible systematic bias in height or form class estimates, no consideration of possible differences in average upper-stem form of trees in the volume table and those on the sale area, and no measure of the variation in volume of the trees on which the volume table was based. Thus, the error of the standard cruise will give an estimate of the limits within which total volume would fall, if all trees had been estimated the same as sample trees.

One other difference between the two samplings was that there were thirty-six three-P sample trees and eighty-eight in the standard cruise. Of course, it took longer to measure the thirty-six trees than to tape diameters and eyeball heights on the eighty-eight trees. However, it would have required 336 trees by the standard cruise method to get an error of estimate as low as that for three-P.

Three-P gross volume estimate was 1,498,000 board feet and standard cruise estimate was 1,860,000 board feet. Gross scale for the sale was 1,508,000 board feet. Of course, scaling is not an accurate means of estimating volume; but its close correspondence to results of dendrometer measurements is encouraging and suggests doing away with the high cost of scaling.

Use of Digital Computers

The computer capability most familiar to research foresters is multiple regression analysis. It used to take many hours to fit by least squares a multiple regression involving four or more variables. Machine programs are available that will screen thirty or forty variables in stepwise or controlled deletion programs to find one or more combinations of the few independent variables that account for most of the variation in the dependent variable. Since few people measure this many variables, the thirty to forty or fewer usually consist of transformations or combinations of measured variables that seem

likely to be better related than untransformed measurements. These programs have been used in soil-site studies, in growth studies, and in other studies to identify transformations of measured variables in a sample with highest coefficient of determination and, hence, with good promise of being the most useful predictors.

A similar computer capability is the production of kinds of multivariate analyses used in econometric and sociological studies. An early application in forestry was discriminant function analysis. However, more and more of these techniques are being applied to forestry data.

The usual least squares methods of fitting equations cannot be used for some of the more flexible growth curves. These require repeated fitting of equations with nonlinear coefficients which can be done quickly on a computer. The simple growth curves that can be fitted by usual least squares methods may have high coefficients of determination but may have no logical interpretation in terms of how trees really grow.

Some mensurationists are old-fashioned enough to want to see their data plotted. This is painless if you use an X-Y plotter. In fact, it's more accurate than hand plotting, and one can plot the dependent variable against all the independent variables, or plot the residuals against the variables in an equation or other variables. These plots quickly reveal correlation of residuals with independent variables and the possible need for weighting. They also can suggest untried functions of independent variables that will fit better than those already tried.

Computers with large memories can digest stem maps with trees located by X-Y coordinates and identified by variables of interest, such as diameter, height, volume, crown size, and growth rate. Such maps can be used in a number of different types of studies. These can be used to study the errors of systematic and other sampling designs, to model stand growth and development, to study effects of clumping and density on growth, and to study alternative intermediate cutting systems.

Tree growth can be simulated in other ways than by this stem mapping procedure. For example, a stand can be broken down into groups of trees that are expected to die or to be removed in intermediate cuts at different stages in stand history. Rules governing progressive changes in competition and growth rates among groups

can be developed empirically or theoretically. This model can then be used to predict probable stand growth and yield. Tests against actual stand remeasurements will demonstrate validity of the model.

Detailed tree measurement data from stands representative of sites and management practices on a large area can be placed on punch cards or on magnetic tape. These become a universal volume table. Whenever a question arises about the potential yield of the property for any product mix, a set of cutting rules can be drawn up specifying which parts of which size trees will go into each product. The stem measurement data are then used to get yields for trees of varying size and these, in turn, are applied to stand tables for the various sites and ages involved.

A new procedure for consistent volume table compilation is feasible. Equations describing average stem profiles and the changes in stem profile related to d. b. h., total height, crown height, and, possibly, other factors can be fitted to tree measurement data. These equations can be integrated between appropriate limits to get cubic volume to any desired top diameter, including or excluding the stump. These equations can also be used to produce taper tables showing for selected tree heights and diameters the d. i. b. at intervals of two feet plus a fraction of trim allowance above stump. Board-foot volume tables can be prepared by giving the machine scaling rules and board-foot equations or tables to apply to these taper tables.

This brief review far from exhausts the ways electronic computers can help in forest mensuration. However, I may have exhausted the patience of those readers not already introduced to analysis methods and computing techniques. Nevertheless, I would like to mention some current general changes in mensuration due to the use of computers.

I think this facility in computing encourages foresters to measure more variables in their site, growth, or other studies. Also, I believe there are more attempts to quantify factors formerly described in qualitative terms. A further quite evident trend is found in field forms, which are now designed for ease of transcription to punch card or tape. Also, there are systems for recording data on cards or tape in the field, most of which will require improvement in means of field editing to detect erroneous records before they become generally useful.

I believe there is a continuing change in regression analysis, from the use of functions that fit batches of data to a search for functions

that have biological meaning. Finally, I expect to see more and more different analysis techniques borrowed from econometrics, engineering, and the social sciences.

This look at what is new in tools and methods in forest measurement suggests that we are a long way from having the instruments we need. However, trials and tests of the few new ones demonstrate both the gains that can be expected when better instruments are available and the need for development of such instruments.

Electronic computers have opened new opportunities for mensuration and silviculture studies which will eventually produce explanations of the complicated processes controlling growth and yield in the forest. The practical outcome of all this will be the ability to forecast with greater certainty the yield of managed forests and to evaluate more precisely the economic feasibility of proposed cultural treatments.

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